Modal Testing as an Aid in Assessing Penetration Mechanic

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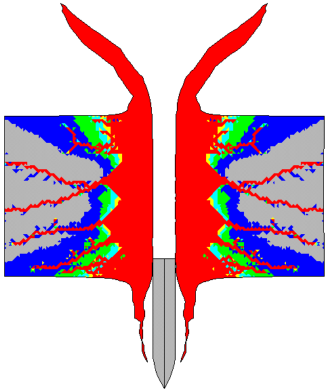

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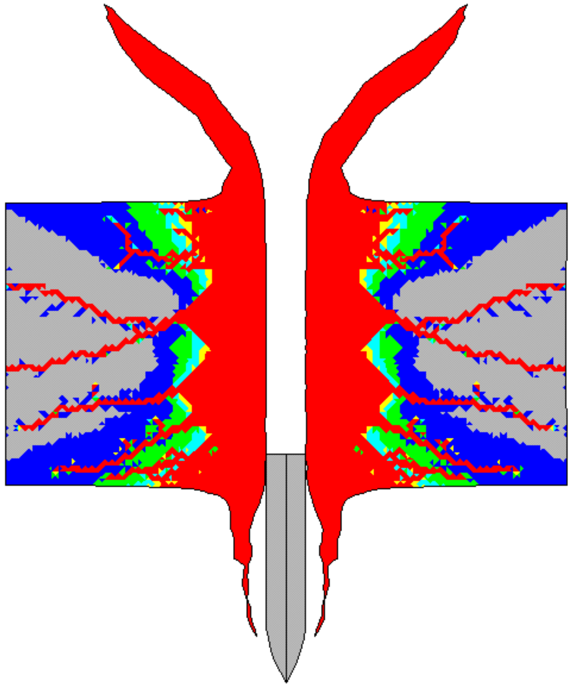
Goals

- Describe a gun-launched earth penetrator test
  - provide test details
  - review and analyze test results
  - draw conclusions concerning analytical/experimental process

- Support program theme
  - measurement system design
    - transducers, system checks, model verification, modal analysis, data filtering, data sampling,

Earth Penetrator Applications

- Deliver ordnance device
- Exploration of geological layer
- Measurement of sea ice thickn
- *Insitu* chemistry
- etc.



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Specific Penetrator to be Field Tested

- length: 61.25”
- diameter: 6.125”
- wall thickness: 1.062”
- weight: 336 pounds
- c.g.: 28.05” from nose
- on board data recording system (accelerometer triggered)
  - resolution: *6 bits (1 part in 63)
  - Nyquist frequency: 11,300 Hz
  - two data channels
    - anti-alias filters designed

** 10 - 12 bit capability today*

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Specific Penetrator (con't)

- two data channels (con't)
  - Micro-Measurements WA 06-250BK-10C strain gages
    (constantan material, 1/4" gage length, temperature
    compensated for steel, fully encapsulated, 1000Ω
    resistance)
    - 180 degrees on circumference, 30" from nose
      - measure compression and bending strain
  - calibrated +/- 6,000$\mu\varepsilon$ (corresponds to yield of
    penetrator steel case [D6 A-C normalized and

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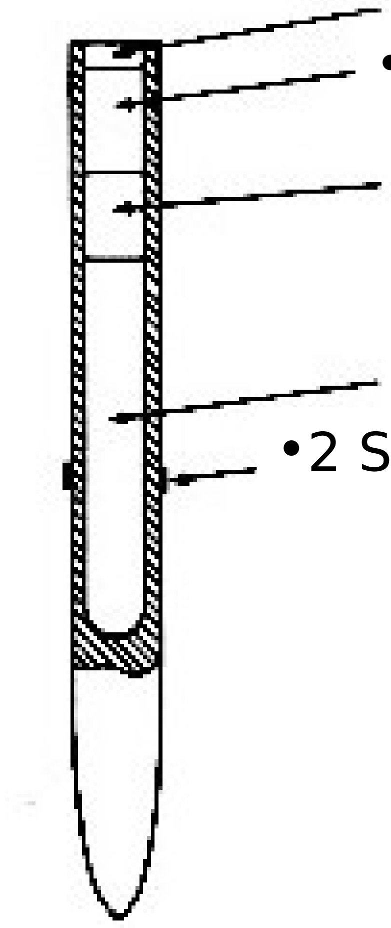
Specific Penetrator (con’t)



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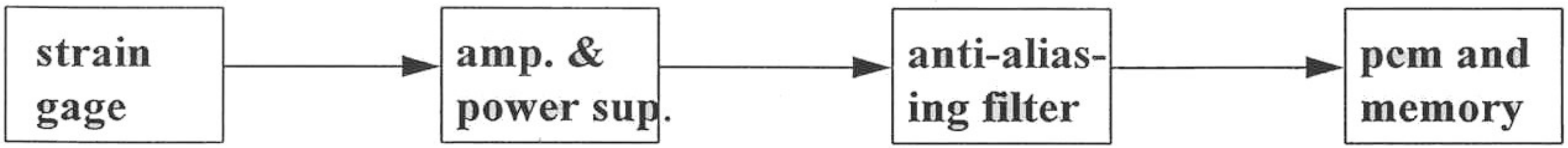
Specific Penetrator (con't)



MM
WA 06-250BK-10C

constantan
1,000 ohm
T. C. 6 ppm/deg F
.250" grid length
encapsulated in glass
fiber reinforced epoxy
phenolic resin

+/- 6,000 microstrain
full scale
~ 211 microstrain/word

- 6dB at 4,200 Hz
24 dB/octave

~48,000 bits
~ 6 bits/word
~179 msec. window
dT/sample for 2
channel system =
.00004417 sec. =
11,300 Hz Nyquist
frequency

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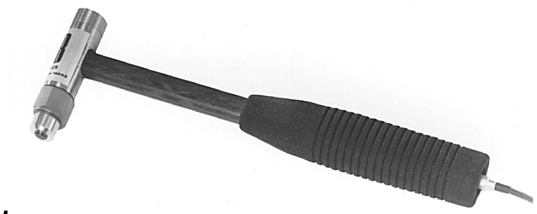
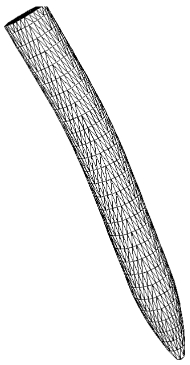
Experimental modal Analysis (review)

- Experimental modal analysis enables extraction of:
  - shape,
  - natural frequency, and
  - damping

  for each vibratory mode of a structu



- Results of experimental modal analysis can be compared to FE codes such as:
  - NASTRAN
  - ANSYS
  - ALGOR



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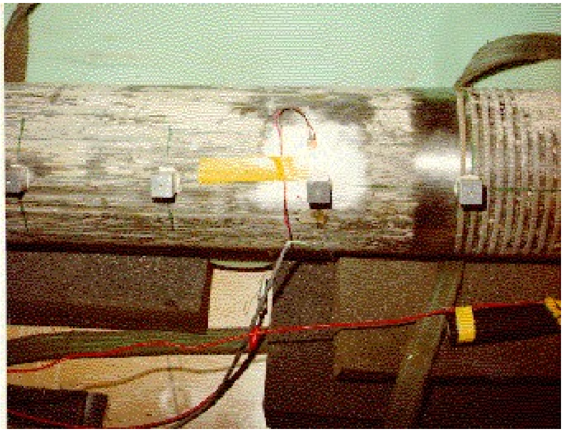
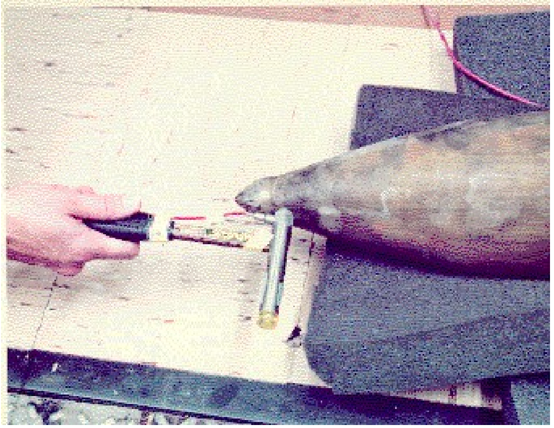
Penetrator Experimental Modal Analysis Results Prior to Field Test



Accelerometer Mounting Locations

Penetrator tested with Free-Free Boundaries



Instrumented Hammer Input

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Penetrator Experimental Modal Analysis Results Prior to Field Test

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deterministic structure adds credibility

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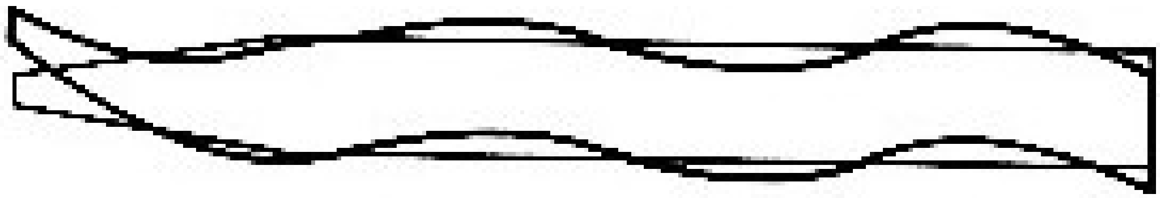
Penetrator Experimental Modal Analysis Results Prior to Field Test



Fourth Bending Mode – 2,713 Hz

Penetrator Natural Frequencies

Bending	Axial
392	1,712
976	3,845
1,764	
2,713	
3,464	
4,368	

Agree with Analytical Model

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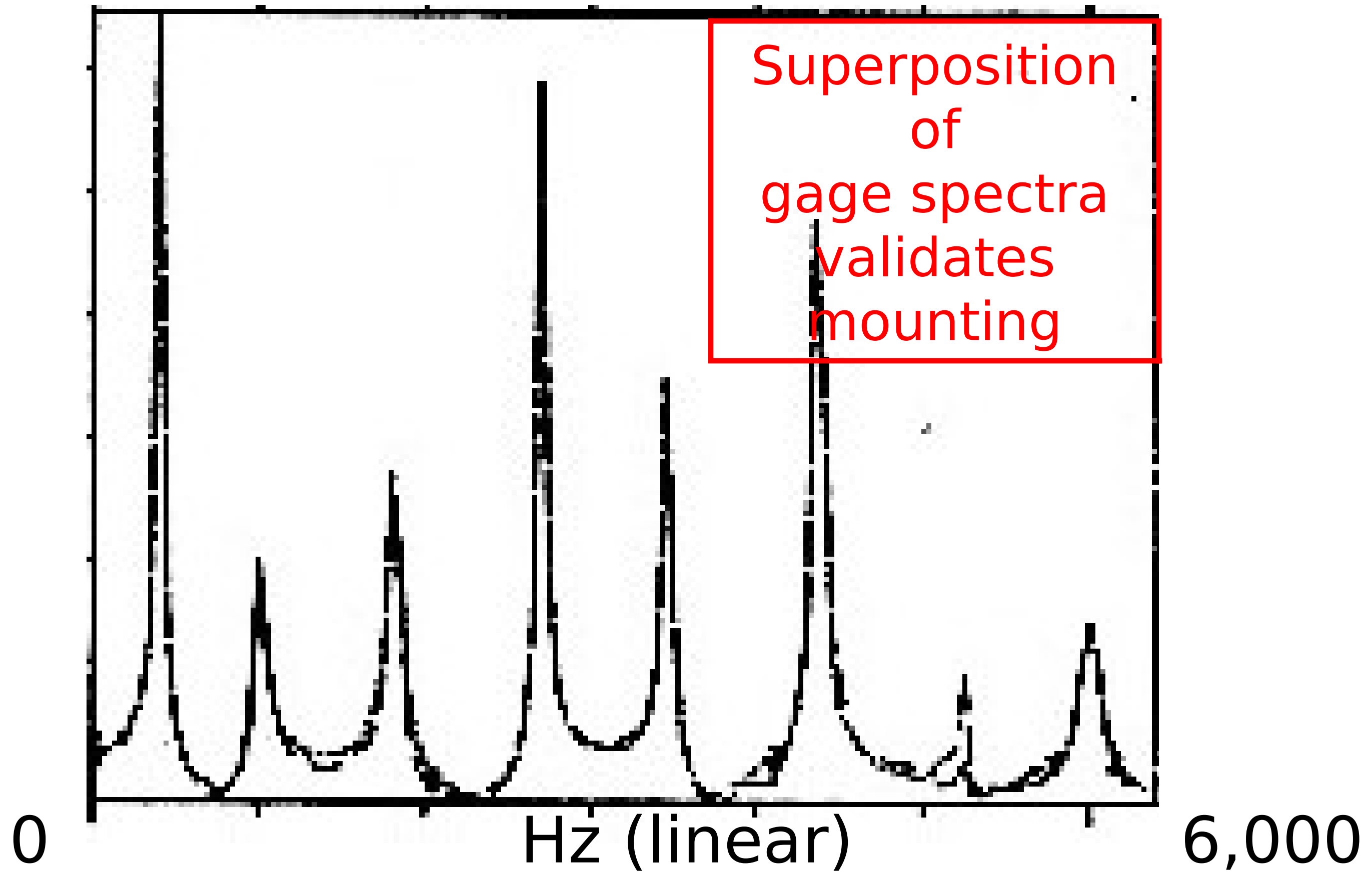
Strain gage Mounting Verification By Modal Test



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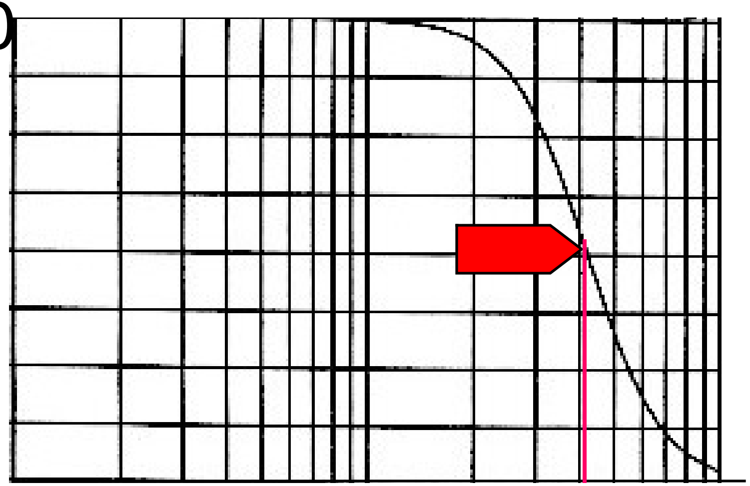
Field Data Recording System Characterization/Verification

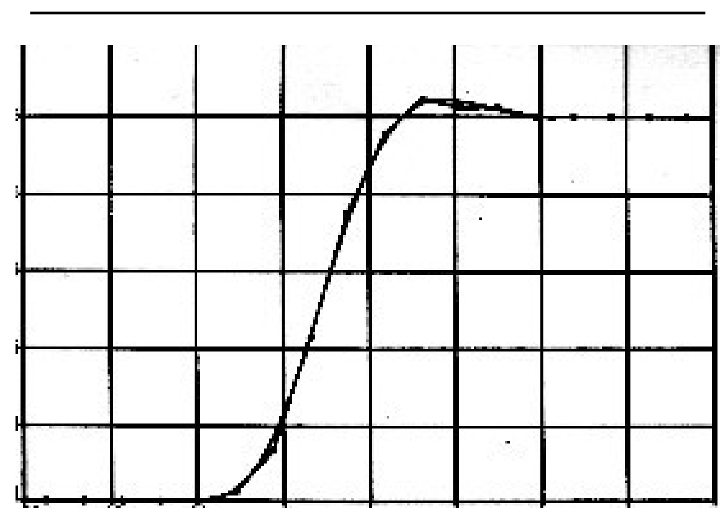
1.0



0 HZ 4,200

AMPLITUDE-FREQUENCY RESPONSE

(2 amplitude levels > linearity verified)



-0.2 0 0.6

msec

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UNIT STEP RESPONSE

(bit resolution 213με)

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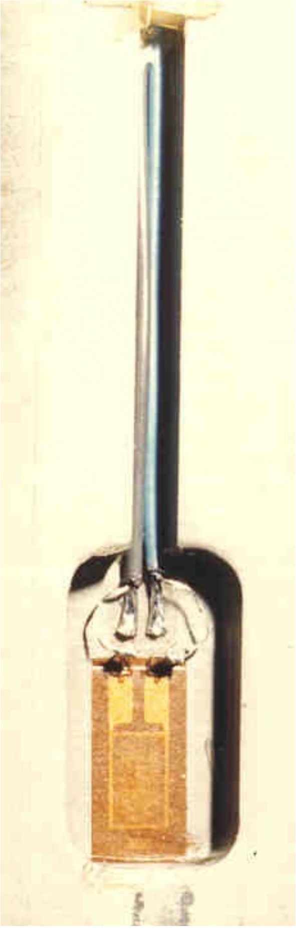
Penetrator Preparation



strain gage mounted
before encapsulation

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Penetrator Preparation

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Penetrator Preparation

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Test Time!!

Davis Gun

- recoilless Cannon
- 2 Deg to Vertical
- pressure data TM from barrel transducer (Kistler 607A in grease filled cavity)
- 93’ dry lake bed target penetration

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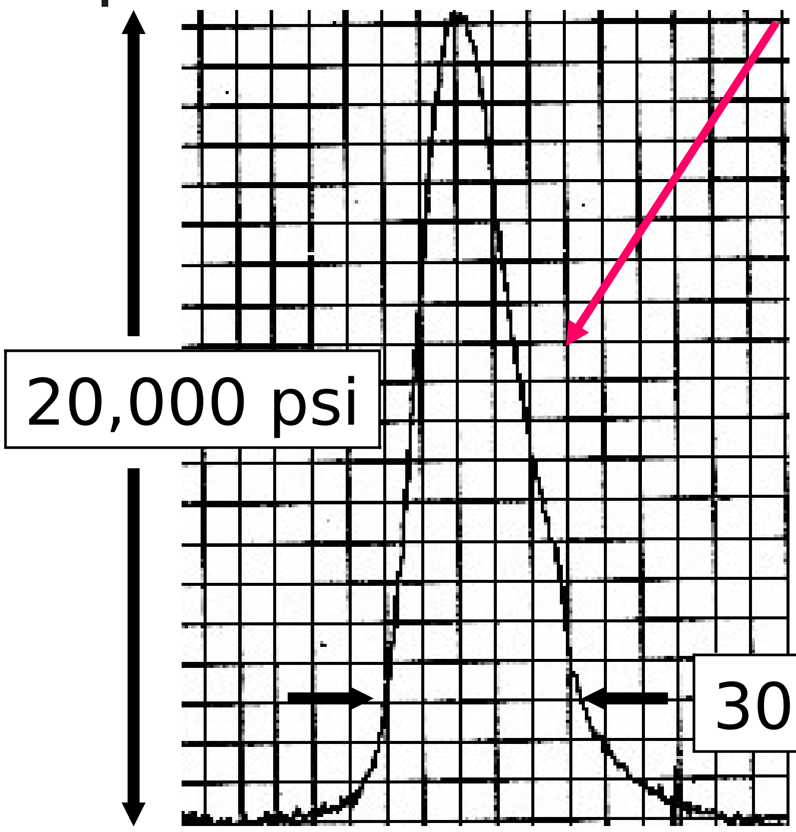
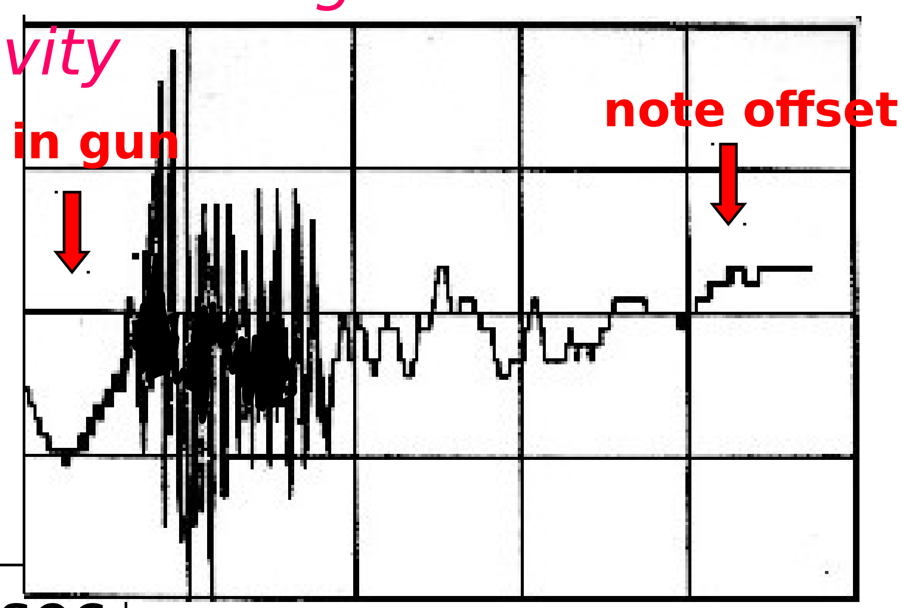
Data Analysis/Validation

From Kistler 607A recess mounted in grease filled cavity



Pressure-Time in Cannon



Data - one of the gages vert +/- 4,000$\mu\varepsilon$ horiz 0-150 msec

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Data Analysis/Validation (con't)

Calculation Consideration:

- from peak pressure in gun:
  - sabot area, yields peak force
- total mass penetrator
  - yields total peak acceleration
- penetrator characteristics:
  - cross section area
  - modulus of elasticity
  - mass in front of strain gage
  - enables calculation of 2,040$\mu\varepsilon$ VS 2,000 - 2,213$\mu\varepsilon$ (within bit resolution)

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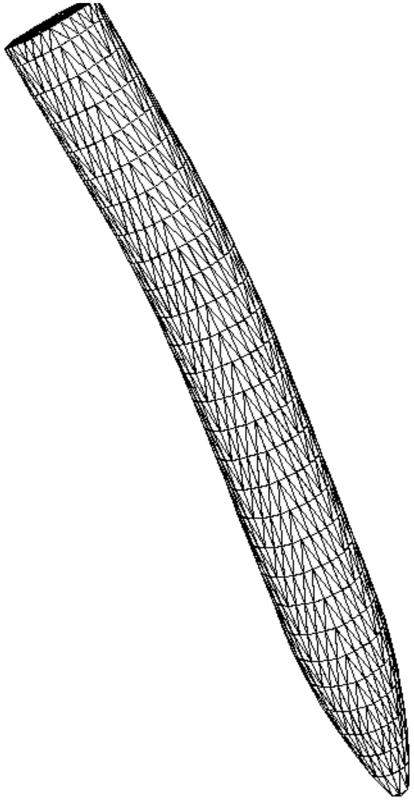
Data Analysis/Validation (con't)

Data offset explanation:



Miners report that penetrator springs back when freed

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Data Analysis/Validation (con't)

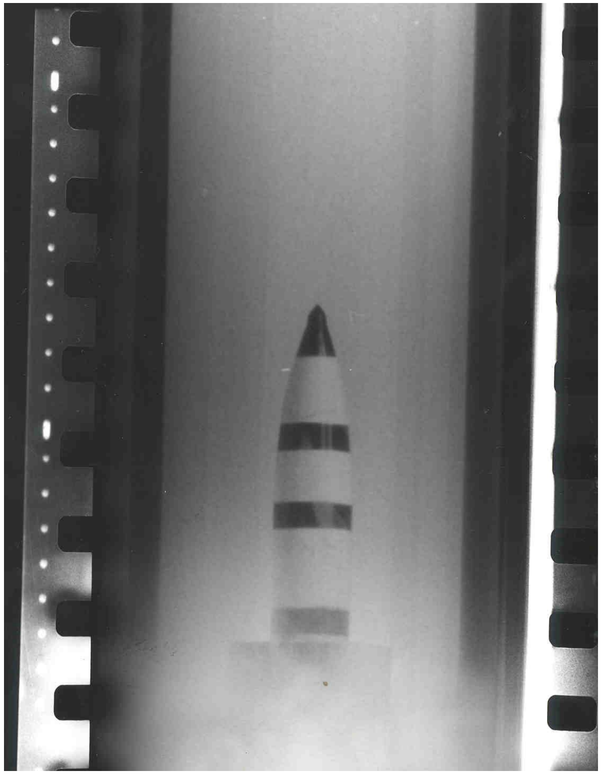

image motion also helps in diagnostics

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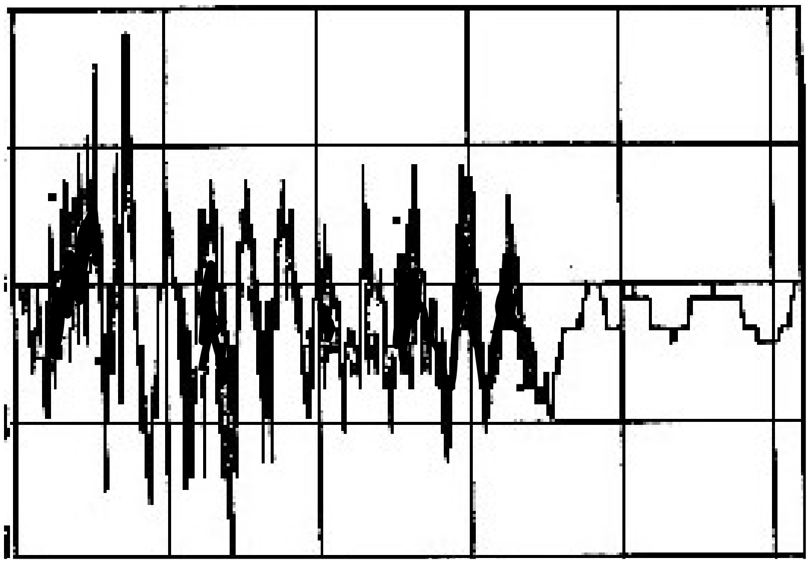
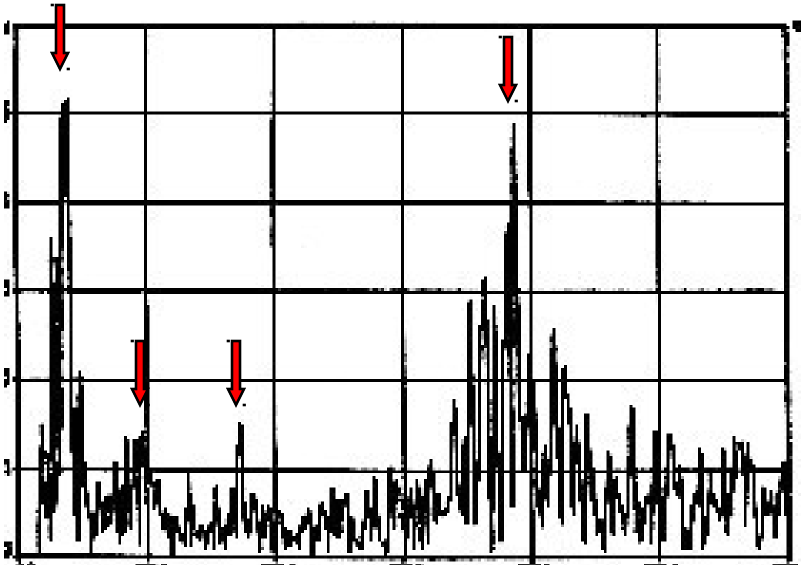
Data Analysis/Validation (con't)



Data Time Expanded - one of the gag
vert +/- 4,000με   horiz 0-73 msec



Fourier transform of same
horiz 0-6,000 Hz
peaks at ~ 392, 976, 1712, & 3845 Hz

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Validates modal test boundary conditions

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Data Analysis/Validation (con't)

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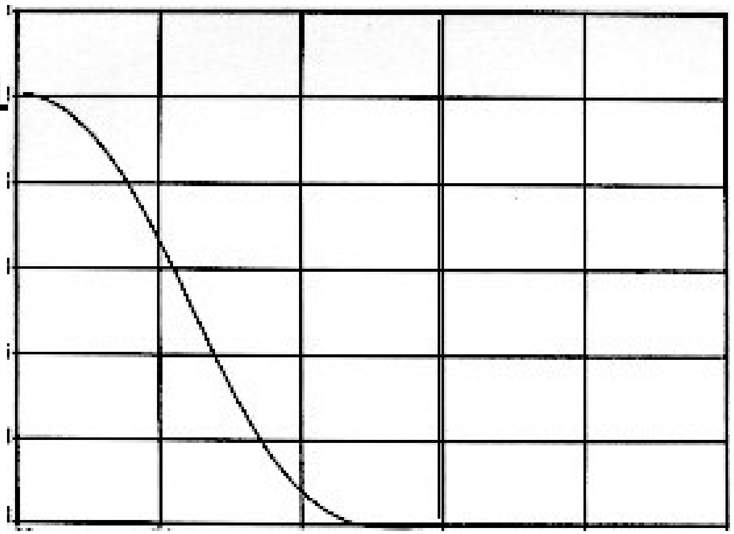
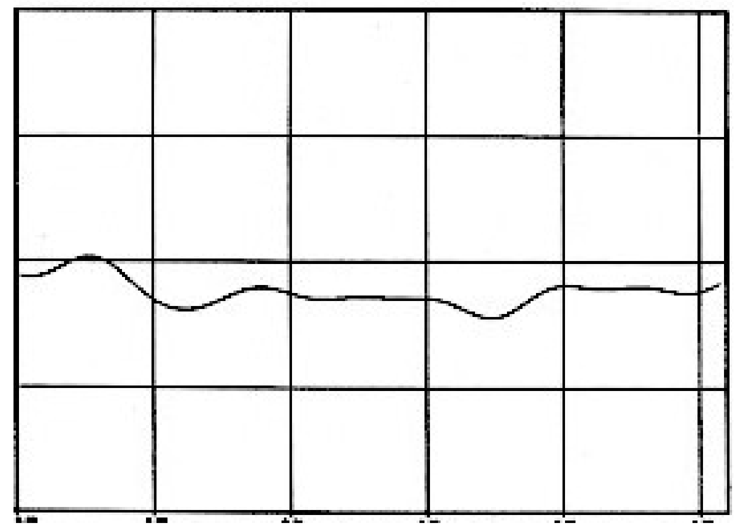


0 HZ 400

Low pass filter preceding data



Penetrator rigid body motion
vert +/- 4,000$\mu\varepsilon$ horiz 0-73 msec

Calculate constant deceleration (assumption) required on penetrator to stop in 93'. Combine with E, cross section area & mass in front of …age to calculate -300$\mu\varepsilon$. <u>Note: within bit …on of above strain levels</u>

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Data Analysis/Validation (con't)

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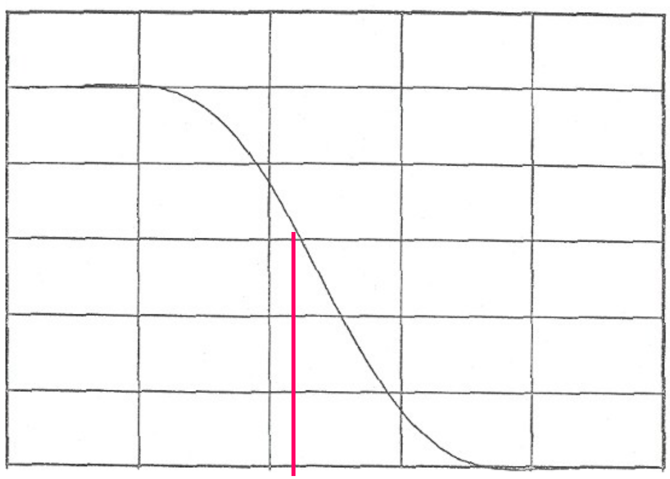
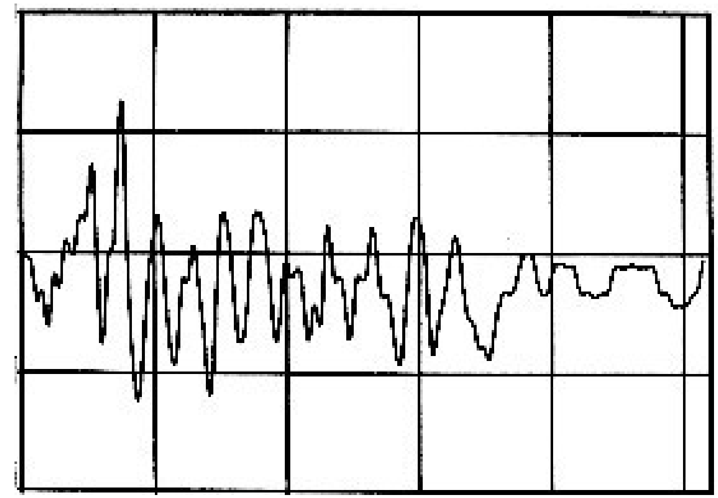


Low pass filter preceding data
(1,100 Hz - 3dB point)



Penetrator bending motion
vert +/- 4,000$\mu\varepsilon$ horiz 0-73 msec

Zero phase shift filter enables waveform subtraction
(see next)

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Data Analysis/Validation (con't)

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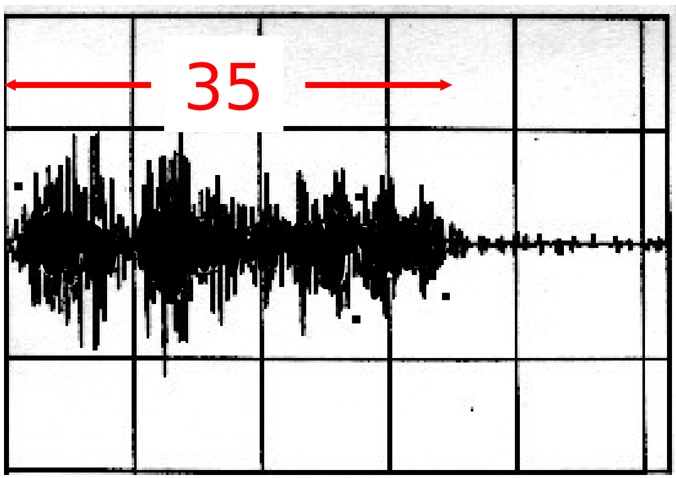
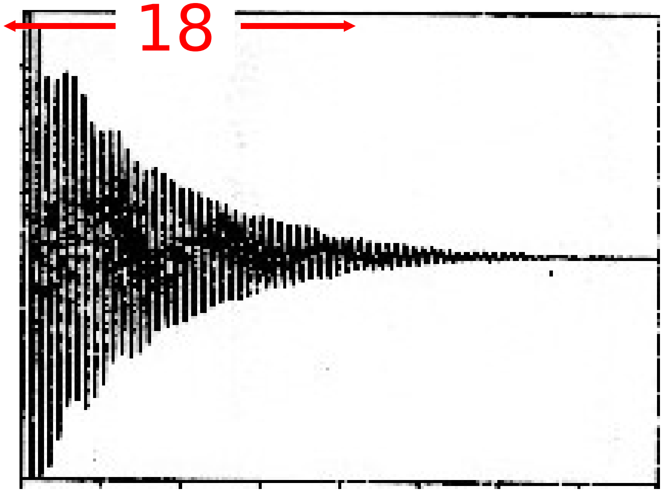


penetrator high frequency Axial motion (subtracted from original data) vert +/- 4,000$\mu\varepsilon$ horiz 0-73 msec



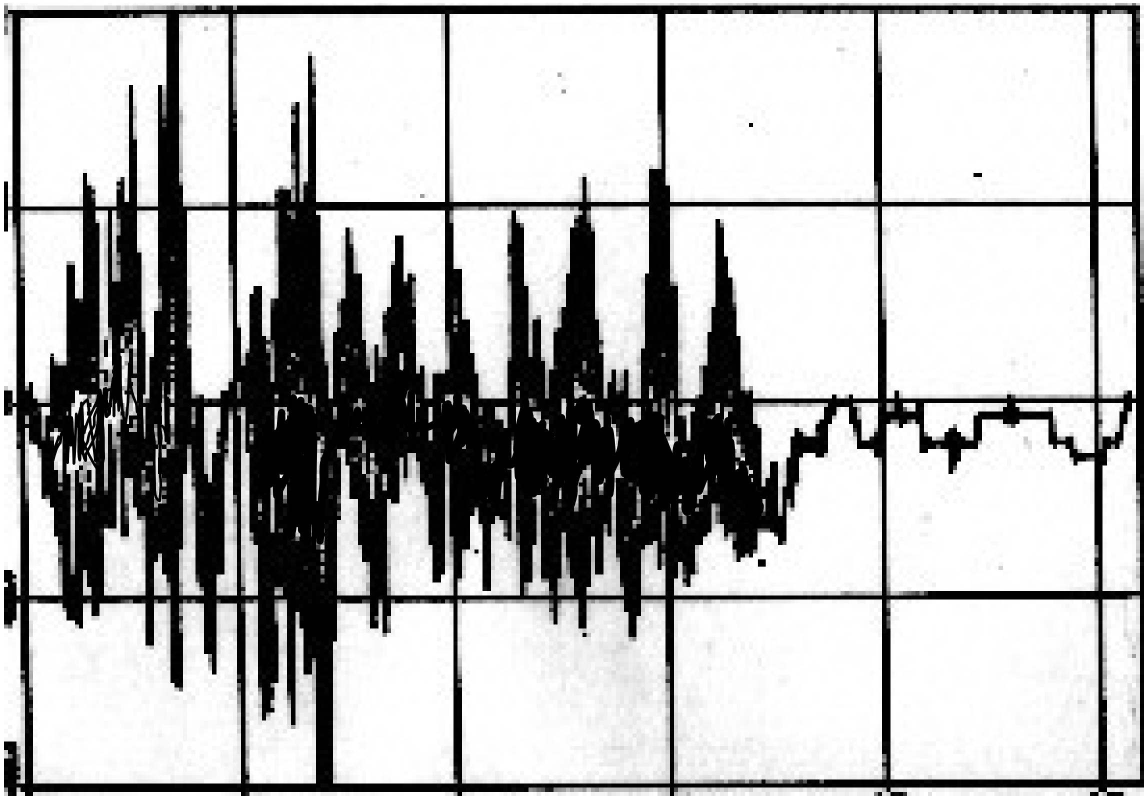
0 msec 40

penetrator modal response to single axial input

Conclusion: High frequency axial loading is occurring ver

many body lengths of penetration.

Data Analysis



Deconvolved Strain Response (unit step used)
vertical +/-6,000με   horiz 0-73 msec

- increased high frequency
- increased amplitud

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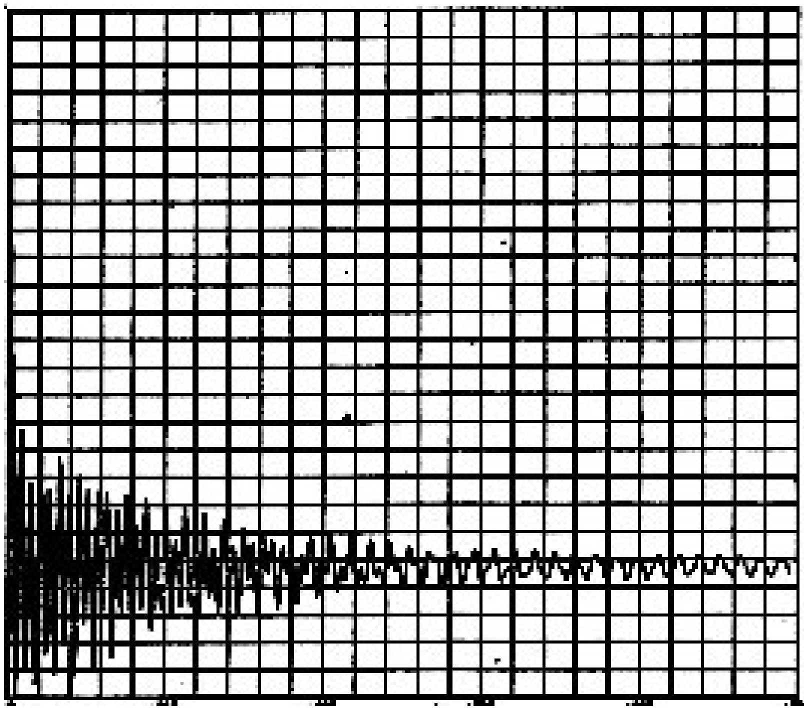
Data Analysis/Pretest Predictions



Analytically predicted test results
vertical +/- 400$\mu\varepsilon$ horiz 0 - 50 msec

- note significant difference
- large bending and axial strains that occurred duri test differed greatly from analytical predictions!

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Conclusions

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- Pretest, experimental modal analysis results agreed with analytical
  structural model.
- Strain gages were verified to be properly mounted.
- Data recording system was dynamically characterized and verified to
  be linear.
- Independent post-test calculations based on pressure-time in gun
  and depth of penetration correlated with measured strain data.
- Significant differences were observed to occur between measured
  and predicted penetrator responses in the field test.

The analytical loads applied to the penetrator in the modeling process were incorrect. Improved analytical results are dependent on more representative models for the soil and soil/penetrator interaction.

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